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Extending Shelf Life of Poultry and Red Meat by Irradiation Processing

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ABSTRACT

Research has demonstrated that ionizing radiation can inactivate parasites, eliminate or greatly reduce the populations of microbial pathogens, and extend the shelf life while preserving the desired nutritional and sensory properties of refrigerated poultry and red meats. Foodborne pathogens can be greatly reduced in population and sometimes completely eliminated from foods by low doses of ionizing radiation. The shelf life of poultry, pork, and beef can be significantly extended by treatment with ionizing radiation. Combination treatments with vacuum packaging or modified atmosphere packaging and ionizing radiation have produced better than predicted results. Additional research is needed on the combined processes.

Meat can be irradiated to eliminate or greatly reduce the numbers of foodborne pathogens, to extend its shelf life, or to produce a sterile shelf-stable product (*33*). Each of these objectives imposes a distinctly different ionizing radiation dose and processing requirement. The purpose of this manuscript is to present evidence for control of foodborne pathogens by doses of ionizing radiation below 10 kGy and to discuss in greater detail the use of the technology to extend shelf life of fresh meats with an emphasis on poultry meat.

Control of foodborne pathogens

The populations of several foodborne parasitic and bacterial pathogens when present on poultry, beef, pork, and other meats can be dramatically decreased or eliminated by treatments with rather modest doses of ionizing radiation. It is also possible by using cryogenic temperatures and vacuum packaging to produce high quality sterile meats by irradiating to the 12D dose for *Clostridium botulinum* (*1,2*).

Very modest doses of ionizing radiation can inactivate the protozoan *Toxoplasma gondii* (0.25 kGy) (*7*), the nematode *Trichinella spiralis* (0. 3 kGy) (*6*), and the cestoda *Cysticercus bovis* and *Cysticercus cellulosae* (0.4-0.6 kGy) (*16*). Toxoplasmosis, though largely unrecognized by the general public, is one of man's most common diseases and is transmitted by ingestion of undercooked pork. *T. gondii* has become increasingly important as an opportunistic pathogen producing disease in the immunocompromized host (*34*). If pork were to be irradiated as permitted since 1985 in the United States (*3,4*) to inactivate *T. spiralis*, *T. gondii* would be inactivated also. *T. spiralis*, when ingested in undercooked pork, bear, and occasionally other meats, causes trichinosis, which may vary in severity from asymptomatic to lethal. Fortunately, trichinosis is quite rare in the United States. The larval stages of the beef and pork tape worms *C. bovis* and *C. cellulosae*, respectively, also are inactivated by radiation doses of less than 1 kGy. Thus, each of these parasitic diseases can readily be controlled by treating meat with ionizing radiation.

The radiation doses required to inactivate 90% (D_{10} value) of several foodborne bacterial pathogens have been determined. *Aeromonas hydrophila* is the causative agent of a mild diarrheal disease and has a D_{10} value of 0.14-0.19 kGy at 2°C in beef (*29*). *Campylobacter jejuni*, which is possibly the most prevalent pathogen associated with poultry, has a D_{10} value of 0.19 kGy at 0 to 5°C in ground turkey (*18*). *Escherichia coli* O157:H7 produces hemorrhagic colitis and has a D_{10} value of 0.27 kGy at 5°C in ground beef (*37*). *Listeria monocytogenes* has a D_{10} value of 0.77 kGy at 2-4°C on chicken (*13*). *Salmonella* spp. have D_{10} values ranging from 0.38 to 0.77 kGy at 2°C in mechanically deboned chicken (*38*). *Staphylococcus aureus* has a D_{10} value of 0.36 kGy in mechanically deboned chicken at 0°C (*36*). *Clostridium botulinum* endospores have a D_{10} value of 3.56 kGy at -30°C on chicken (2). A D_{10} value is given at -30°C for *C. botulinum* because control of this organism generally requires commercial sterility and that requires low temperatures to retain the desired organoleptic properties. There are exceptions to this, however, and a D_{10} value must be carefully determined considering both product and processing temperatures.

There is concern that irradiation will decrease the normal microbial flora of chicken to such an extent that pathogens such as *Salmonella* species will be able to grow rapidly under abuse conditions. Szczawińska et al. (*35*) tested this concept by inoculating mechanically deboned chicken meat with challenge doses of three different serovars of *Salmonella* following irradiation of the meat to 0, 1.25, or 2.5 kGy and storing the inoculated meat at 0, 10, or 20°C. *Salmonella* populations did not increase more rapidly even in those samples that had received a dose of 2.5 kGy than in the controls.

Poultry irradiation

The concept of preserving poultry and meat by irradiation is not new. In 1929 a patent was issued in France for food preservation by processing with high energy radiation (*28*). There was also a very early realization that the radiation dose required to inactivate bacteria was dependent on the type of radiation, the temperature of irradiation, the atmosphere, and the nature of the suspending medium (*28*). A number of studies of shelf-life extension of

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chicken meat (*30*) and prepackaged fresh beef (*9*) were initiated shortly after World War II ended. Proctor et al. (*30*) found that nonirradiated chicken meat stored at 2-4.4°C for l week had spoiled and had a standard plate count of 4.8×10^7, but chicken meat irradiated to a dose of 7.4 kGy, using a 3 Mev electron beam, was still acceptable after 4 weeks of storage at 2-4.4°C. At this dose, however, there was a significant radiation effect on flavor. Vacuum-packed and frozen samples of chicken meat irradiated to doses of 18.6 kGy were not significantly different in flavor from controls. It was soon realized that meats subjected to sterilization doses of ionizing radiation must be irradiated in the frozen state and in the absence of air to retain the desired sensory properties, and for this reason this discussion will be limited to nonsterilization doses.

Thornley (*40*) irradiated vacuum-packed minced chicken meat at room temperature to a dose of 2.5 kGy. Some irradiated samples remained wholesome after 80 d storage at 5°C. McGill et al. (*24*) irradiated whole eviscerated chicken carcasses in polyethylene bags packed in ice using a cobalt radiation source to zero, 0.93, and 4.65 kGy. Carcasses were stored at -22, 1, 4.4, and 10°C until spoilage occurred, as determined by bacteriological and physical examination. The unirradiated carcasses stored at 1°C were spoiled after 11 d, but the carcasses that received 0.93 kGy required 20 d to spoil. The carcasses that received 4.65 kGy were not considered spoiled at 20 d. Storage at 1 rather than 4.4°C reduced the formation of rancidity. A sensory panel was unable to distinguish between unirradiated and irradiated (0.93 or 4.65 kGy) baked dark or white chicken meat after storage at 1°C for 2 or 7 d.

Mercuri et al. (*25*) conducted a study of tray-packed cut-up fryer chickens irradiated with gamma rays from ^{60}Co to a dose of 0, 1.0, 3.0, and 5.0 kGy at ice or dry-ice temperatures and storage of the controls and irradiated samples at 1.1 or 4.4°C for up to 21 d. They reported that a dose of 3.0 kGy was optimum for extension of refrigerated shelf life whether the chicken was stored at 1.1 or 4.4°C. They recommended that though such chickens had a minimum shelf life of 21 d, that 14 d be considered optimal as there was a tendency for the product to develop slight to moderate off-odors after approximately 2 weeks. The chickens irradiated while frozen had increased bacterial counts and exhibited odors sooner than did those irradiated in the fresh state. The odor of raw and roasted thighs from the 3.0 kGy treated chickens refrigerated for 2 weeks compared favorably with unirradiated, unstored samples.

Idziak and Incze (*14*) irradiated 2-3 lb (ca. 0.907 kg) broilers at room temperature using a cobalt source to doses of 0, 2.5, 5.0, and 7.0 kGy and stored the chicken at 5°C. On the basis of microbial loads, they estimated that a 5-kGy treatment extended the shelf life to 16 to 20 d; a dose of 7 kGy extended it to 19 to 24 d compared to 6 to 9 d for the unirradiated carcasses. Unfortunately, the carcasses that received 2.5 kGy were not evaluated at 5°C, and no organoleptic tests were performed.

MacLeod et al. (22) found that six expert panelists correctly differentiated between roasted dark or white chicken meat after irradiation to 4.6 kGy and storage for 0, 1, 2, or 3 weeks at 6.7°C or 1.1°C from nonstored, fresh chicken meat as the control in triangle tests based on odor, texture, and taste. However, the authors irradiated the chicken without any temperature control, and only a single carcass provided the meat for each experimental variable. Nonirradiated controls stored for the same periods under identical conditions were not included in the comparisons.

Kahan and Howker (*15*) irradiated fresh eviscerated broiler chickens, both with and without salt treatment (kosher processing), and stored the treated carcasses at -1.0, +1.6, and +4.4°C for up to 31 d. Seven irradiation doses were evaluated: 0, 1.2, 2.0, 2.5, 2.8, 5.0, and 5.6 kGy. Samples were withdrawn at intervals for microbial, physical, and sensory evaluations. They concluded that a combination of 2.5 kGy and storage at 1.6°C extended shelf life to 15 d without deleterious effects on color, odor, or taste.

Klinger et al. (*17*) and Basker et al. (*5*) irradiated tray-packed koshered broilers, leg meat, and breast meat packed in ice to doses of 2, 3 3.75, and 4.5 kGy. Evaluations of samples irradiated to 3.7 kGy immediately after treatment indicated that there was no difference in sensory quality between irradiated and nonirradiated boiled chicken meat. Sensory differences became noticeable as storage time at 1-2°C increased. They concluded that the quality of the chilled irradiated leg meat was acceptable for about 2 weeks and the breast meat for about 3 weeks.

Hanis et al. (*12*) evaluated the organoleptic characteristics of raw, boiled, and fried poultry meat 48 h after irradiation at -15 or +10°C in polyethylene bags to doses of 0, 0.5, 1.0, 2.5, 5.0, or 10.0 kGy. A characteristic dose and temperature-dependent odor was observed. Boiling or frying diminished or eliminated the negative sensory effects of irradiation. The authors considered boiled chicken meat to be acceptable and fried chicken meat to be very good after a dose of 10 kGy. The acid value of the extracted fat increased 4.5% and the peroxide value 136% after a dose of 2.5 kGy at 10°C.

Lescano et al. (*21*) irradiated chicken half breasts with bone and skin wrapped with polyvinyl chloride film and packed in polystyrene trays to doses of 0, 2.5, 3.0, 3.8, or 4.5 kGy at ambient temperature. The aerobic bacterial counts of the samples that received 2.5 kGy reached 10^6 CFU/g by d 19 of storage at 2°C, and the panel considered the sensory properties good up to day 22. Reduced levels of rancidity, release of fatty acids, and waterholding capacity were found in the irradiated samples. Control samples reached 10^6 CFU/g by day 8. The raw meat had a slight pinkish color and an unpleasant irradiation odor which was not noticeable after oven cooking. Chicken samples treated at doses greater than 2.5 kGy were considered organoleptically good up to day 22, but flavor and acceptability scores were lower.

Shamsuzzaman et al. (*32*) vacuum-packaged skinless and boneless chicken breasts in polyethylene bags. The chicken samples were heated to an internal temperature of 65.6°C either before or after irradiation with 10-MeV electrons to doses of 0, 1.1, 2.2, or 2.9 kGy. The samples were covered with ice during irradiation. After irradiation the samples were stored at 2°C for 0, 2, 4, 6, or 8 weeks before microbiological, vitamin, and sensory analysis. Some samples were inoculated with *L. monocytogenes*. The heating and vacuum-packaging "sous-vide" process had little effect on *L. monocytogenes*, and the residual inoculum reached 10^7 CFU/g after 8 weeks of storage at 2°C. However, after treatment with 2.9 kGy combined with the "sous-vide" process, *L. monocytogenes* remained undetectable during the 8-week storage period. The combination of irradiation with heating and vacuum packaging produced a much greater effect than would be predicted from the results obtained from either treatment alone. This is similar to results reported by Thayer et al. (*39*) with *Salmonella typhimurium*. Microbiological, vitamin, and sensory analyses indicated that unirradiated samples treated with the "sous-vide" process had a shelf life of less than 6 weeks, but samples irradiated to 2.9 kGy had a shelf life of at least 8 weeks with little effect on the odor and flavor and only a slight reduction in thiamin content.

Meat irradiation

The effects of low doses of ionizing radiation on the properties of beef have been investigated. Tiwari and Maxcy (*41*) reported substantial reductions in the total number of aerobic mesophilic bacteria on ground beef that had been irradiated to 0.68 kGy and stored at either 2°C or 5°C for periods of up to 16 d. The nonirradiated samples reached a count of 10^9/g in 6 d at 5°C, whereas the samples irradiated to 0.68 kGy reached only 2.6×10^6/g in the same period. Urbain and Giddings (*42*) reported that the number of aerobic mesophilic bacteria on irradiated (2.5 kGy) vacuum-packaged beefsteaks did not exceed 10^4/g during 21 d storage at 4°C. They concluded that meats treated with phosphate retained better color and acceptance ratings, and that air should be excluded from the product. Urbain (*43*) reported that steak treated with phosphate, vacuum packaged, and irradiated to 1.0 kGy retained satisfactory microbiological quality after 21 d storage at 4°C and scored equally as well as fresh untreated steak for odor, flavor, juiciness, and overall quality. Niemand et al. (*26*) vacuum packaged sirloin steak in oxygen-permeable laminated bags and irradiated the samples to 0 or 2 kGy at 25°C. All samples were then stored at 4°C until withdrawn for sampling. They concluded that a shelf life of up to 10 weeks could be expected for the irradiated samples, twice that of the unirradiated samples. The flavor of the stored irradiated samples was improved by irradiation at 0 to 2°C. Niemand et al. (*27*) investigated the effects of 2.5 kGy, lactic acid, and the combination of lactic acid and irradiation on minced beef samples stored at 4°C. The population of aerobic bacteria in the vacuum-packed control samples reached 10^7/g in 4 d, whereas the population in the vacuum-packed irradiated plus lactic acid-treated samples did not exceed 10^4/g during 21 d of storage. Risvik (*31*) conducted a sensory evaluation of vacuum-packed beef rumpsteak gamma irradiated at ambient temperature to doses of 0, 1.0, 2.5, 5.0, and 10.0 kGy before and after storage for 3 months at 4°C. All irradiated samples had significantly different sensory properties from unirradiated controls both immediately after irradiation and after storage. Dose-related odor, off-taste, rancidity, metallic taste, and sweetness were noted. After 3 months storage, all irradiated samples were unsuitable for consumption; however, this author notes, the samples that received 1.0 and 2.5 kGy had total viable bacterial counts in excess of 10^9/ml of meat juice and should have been considered spoiled and not evaluated by a sensory panel.

Mattison et al. (*23*) investigated the effects of a 1.0 kGy gamma radiation dose at ambient temperature on the microflora and sensory properties of vacuum-packaged pork loins over a storage period of up to 21 d at 4°C. The 1-kGy dose was selected because this is the approved maximum treatment for control of trichinae larvae. Irradiation lowered the numbers of bacteria, and after 14 d storage there were no detectable sensory differences between irradiated and nonirradiated pork. Ehioba et al. (*8*) reported that a radiation dose of 1 kGy extended the shelf life of vacuum-packaged ground pork by 2.5-3.5 d. Lebepe et al. (*20*) irradiated vacuum-packed pork loins at ambient temperature to 3.0 kGy and evaluated the effects on the microflora during storage at 2-4°C. They concluded that the 3-kGy treatment extended the shelf life of vacuum-packaged pork loins to more than 90 d compared to 41 for nonirradiated loins. There was no evidence that the spoilage of the irradiated pork loins differed from that of the nonirradiated loins. Chemical spoilage began at 91 d in the loins stored at 2-4°C.

Grant and Patterson (*10*) investigated the combination of irradiation (1.75 kGy) with modified atmosphere packaging (MAP) on the microbiological quality, color, and odor of pork stored at 4°C. A mixture of 25% CO_2 and 75% N_2 was recommended to improve the microbiological and sensory quality of the irradiated pork chops. Grant and Patterson (*11*) concluded from a study of minced pork packed in 25% CO_2 and 75% N_2 and then irradiated to 1.75 kGy that the irradiated MAP pork was microbiologically safer than the nonirradiated MAP pork. Lambert et al. (*19*) concluded that *Clostridium botulinum* toxin production occurred faster in inoculated fresh pork using MAP concentrations of CO_2 of 30% or less. A 1-kGy radiation dose with 45-75% CO_2 MAP delayed toxin production.

Temperature control during irradiation in the studies by Mattison et al. (*23*) and by Lebepe et al. (*20*) was either minimal or lacking entirely. Mattison et al. (*23*) state that the temperature of the samples upon arrival at the radiation source was 0°C. However, the irradiation required 207 min, and no temperature measurements of the samples immediately following irradiation were reported. Adverse effects of irradiation temperatures from 5 to 10°C have been reported on the flavor of pork, beef, and chicken (*44*). Mattison et al. (*23*) reported excellent results from their studies; could better results have been obtained by these and other workers by maintenance of irradiation temperature between 0 and 5°C as was reported by Nieman et al. (*26*)?

CONCLUSION

Improved shelf life of meat can be obtained by irradiation, particularly in *vacuo*. If vacuum packaging is used, however, there is concern about the potential for outgrowth and toxin production by *C. botulinum*. Irradiation's chief advantage is the increased microbiological safety of its product, and its use to extend shelf life must be done only without compromising safety. Significant shelf-life extensions of MAP poultry are routinely obtained by industry, and the effect of the combination of MAP with irradiation appears to have received little if any attention by investigators. The combination of MAP with irradiation of beef also has not been extensively investigated. The combination of MAP with irradiation of pork has been investigated with promising results. It is also apparent that greater attention should be given to the temperature of the products during the irradiation process to produce optimum sensory properties. It seems very probable that the combination of modern packaging techniques and ionizing irradiation will increase shelf life of meats significantly.

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